

## Strengthening of Bridge G270 with Externally-Bonded CFRP Reinforcement

### Description:

This report presents the results of a pilot study to apply externally bonded Carbon Fiber Reinforced Polymer (CFRP) sheets to strengthen a simple span reinforced concrete solid slab bridge. Strengthening with CFRP sheets was accomplished in three days without traffic interruption. Preparation consisted of light sandblasting and no concrete repair.

The objective was to remove the current load posting. This bridge is a load posted structure on a heavy truck route. The University of Missouri at Rolla conducted the pilot study for the Missouri Department of Transportation. The testing procedure included the construction of two test beams, to simulate bridge deck performance with and without strengthening. Laboratory setup, instrumentation and test results of two full-scale test beams are presented. Field load tests of the bridge were performed by the University of Missouri at Columbia to verify the increase in flexural strength achieved with the application of externally bonded CFRP. The method used to field load test the bridge along with the subsequence load-deflection characteristics is presented. Comparisons are made between the analytical model, laboratory beam specimens strengthened with CFRP, and in-situ field tests of the actual bridge before and after strengthening.

### Selection of Bridge G270:

The bridge selected for demonstration of the CFRP strengthening technology was Bridge G270 located on Route 32 in Iron County. It is a 20 foot solid reinforced concrete slab built in 1922 with an original roadway width of 18 feet. The bridge currently carries a traffic volume of 1600 vehicles per day. Around 1990 the original baluster handrails were removed and replaced with a thrie-beam guardrail, which expanded the roadway width to approximately 20 ft. The bridge has a load restriction posting of 19 tons for H20 trucks and 34 ton weight limit for all others. Due to the restricted load posting and its location near a lead mine, a generator of heavy truck traffic, MoDOT selected this bridge for evaluation.

### Objective:

The objective was to increase the load carrying capacity of bridge G270, with the application of CFRP, to allow the removal of the bridge's restricted load posting. Verification was accomplished by comparisons made between the analytical model, laboratory beam specimens strengthened with CFRP, and in-situ field tests of the actual bridge before and after strengthening.

### CFRP Selection:

The "as built" moment capacity of the bridge was 20% below that required for today's traffic loads. It was reasonable that the CFRP composite strengthening system would be

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capable of correcting this deficiency. MBraceä CF-130 is selected for this application with a tensile modulus of 33 msi and a tensile ultimate strength of 550 ksi and a thickness of 0.0065 inches.

### Experimentation:

Since bridge G270 was still in service applying CFRP and testing to failure was not an option. The option chosen was to construct a full-scale beam section that could be tested in the laboratory to failure. Copies of the original bridge plans were reviewed to determine the geometry, reinforcement layout and material properties of the bridge.

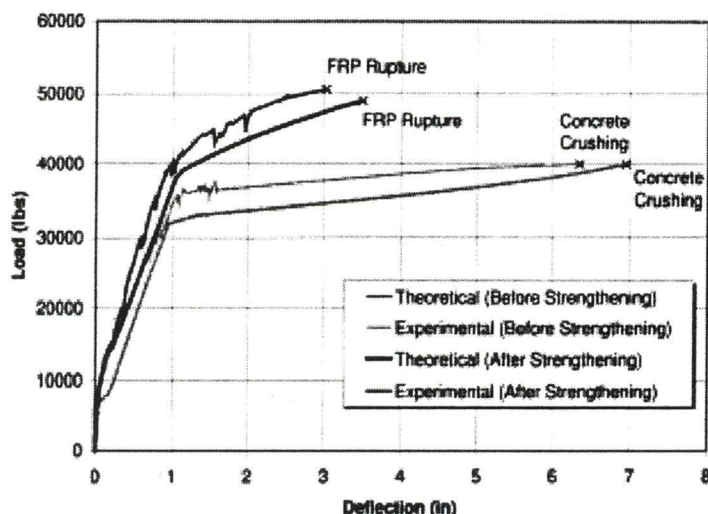
Through laboratory testing the amount of CFRP required to gain a 20% increase in flexural strength was determined. This would be the equivalent increase in strength needed in the existing structure, using MoDOT's rating criteria, to remove the load posting.

Two beams were built for laboratory testing. One beam was tested to failure without strengthening for baseline comparisons. The second beam was strengthened using one ply of CFRP.

### Load-Deflection Characteristics:

The load deflection curves in Figure 1 show the correlation between the theoretical design equations and the experimental results. The curves show the design methodology

**Figure 1**  
**Load Deflection Characteristics of Test Beams**



used is effective in determining the strength and failure modes of the reinforced concrete beams. The failure modes, as predicted, were crushing of the concrete and rupture of the CFRP respectively.

### Application of CFRP:

Grout lines on the bottom surface of the bridge were ground smooth with hand grinders and the entire slab was lightly sand blasted to remove any loose material.

The layout pattern consisted of eight sheets of CFRP, 20 in. wide, alternating with a 3 in. gap. Six sheets were used for strengthening the two additional sheets of CFRP were added for destructive test purposes.

A two-part epoxy primer was applied to the concrete surface where the CFRP was to be applied and allowed to cure approximately twelve hours. Then epoxy putty was applied it serves to smooth out any remaining imperfections. Immediately after the putty was applied, the first coat of epoxy saturant was applied over the entire area that was to receive one strip of CFRP. Next a strip of CFRP was measured, cut and applied in a fashion similar to wallpaper. One end of the CFRP sheet was placed on the slab and pressed into the saturant while a second person applied the remainder of the sheet forcing it into the saturant in one continuous movement. To ensure proper embedment into the saturant and to remove any entrapped air the entire surface of the CFRP was pressed into the saturant with a small hand roller. The last step was to apply the final coat of epoxy saturant over the CFRP. The entire process was completed in three days including instrumentation and testing.

### Instrumentation:

The load testing equipment used to field test the elastic deflection response was provided by the University of Missouri-Columbia. The vehicle used to load the bridge consisted of a flatbed truck loaded with 21.14 tons of steel weights.

### Load Testing:

Load-deflection testing on the bridge was performed before and after the application of CFRP. Deflection tests were performed by driving the loaded truck over the bridge. The test truck made six passes over the bridge. The truck drove forward and backward on the south side, north side and centerline of the bridge. Each time the truck passed over the bridge the deflection readings were measured and recorded. Load Deflection Observations: Table 1 contains the tabulated results of the bridge deck deflections before and after strengthening with CFRP. The average deflection measurements after strengthening were 94%

**Table 1**  
**Deflections Before and After Strengthening**

Bridge Condition	Truck Path	LVDT Deflections (inches)				
		#1	#2	#3	#4	#5
Not Strengthened	North	0.0068	0.0143	0.0087	0.0054	0.0067
	Middle	0.0070	0.0098	0.0091	0.0080	0.0069
	South	0.0059	0.0064	0.0074	0.0092	0.0058
Strengthened with FRP	North	0.0063	0.0130	0.0086	0.0051	0.0063
	Middle	0.0067	0.0086	0.0090	0.0080	0.0066
	South	0.0054	0.0049	0.0073	0.0095	0.0054
After/Before	North	0.927	0.909	0.989	0.944	0.940
	Middle	0.957	0.878	0.989	0	0.957
	South	0.915	0.766	0.986	1.033	0.931

of the original. As seen from the data, deflections were not uniform. The north side of the bridge deck had some deterioration and spalling which produced the area of greatest deflections. This area, as a result of strengthening, showed the greatest reduction in the amount of live load deflection.

**Conclusion:**

This project demonstrates the feasibility of using externally bonded CFRP as a means to repair and rehabilitate reinforced concrete structures. Externally bonded CFRP sheets are an effective technique to enhance the flexural capacity of RC beams. The laboratory test of the two full-scale beams showed the expected increase in flexural capacity was achieved. The load-deflection behavior of the strength-

ened beam could be analytically predicted with good accuracy using the classic approach for RC sections.

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